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USAF, 1 May 1950

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SCIENTIFIC ADVISORY BOARD TO THE CHIEF OF STAFF, USAF

Progress Report on the  
Air Defense Systems Engineering Committee (U)  
1 May 1950

ARCHIVES INVENTORY
G.E. VALLEY
1 MARCH 97
1967
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1987

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ADSEC

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TABLE OF CONTENTS

	Page
I. <u>ORIGIN AND BACKGROUND</u>	1
II. <u>MEMBERSHIP AND MODE OF OPERATION</u>	2
III. <u>THE AIR FORCE'S PRESENTLY PLANNED AIR DEFENSE SYSTEM</u>	4
A. Mode of Operation	4
B. Materiel of Present System on Hand	6
C. Materiel Proposed for Present System	8
IV. <u>PROPOSED ADSEC "MODEL" GROUND CONTROL</u>	9
A. Basic Ideas Underlying Proposed System	10
B. Observation Posts	11
C. Data Analysers	13
D. Telephone System	14
E. Method of Operation	14
F. Over-water Coverage	15
G. Use of Present Equipment	15
H. Recommendations	15
I. Interceptor Control Equipment	16
V. <u>OTHER DEVELOPMENTS</u>	17
VI. <u>PROJECT BUDGET</u>	17

Appendix A

Appendix B

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I. ORIGIN AND BACKGROUND

On 28 November, 1949 the Vice Chief of Staff called a special meeting of the Executive Committee of the Scientific Advisory Board and asked the Board's consideration of certain vital problems in the field of air defense of the Continental United States.

To study these problems in detail and to determine effective solutions, Dr. Theodore von Karman, Chairman of the Scientific Advisory Board, proposed the formation of an air defense technical committee. His memorandum to the Vice-Chief of Staff dated 29 November, 1949, contained the following recommendations regarding the assignment of such a committee:

"This would be a continuing, small-scale, technical activity, working in close cooperation with an experimental tactical unit (about the size of a squadron), which would be established and stationed in the Northeast where the required assistance from Board members and other scientists can be made readily available."

"The general objective of this group would be the operational development of equipment and techniques -- on an air defense system basis -- so as to produce maximum effective air defense for a minimum dollar investment."

"I feel strongly that the need for an activity of this sort is urgent and should be considered quite apart from the immediate, high-level decisions which the Air Force must make. This Committee will help determine quantitative, factual data concerning current and future operational techniques and equipment, for use in the periodic reviews

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of air defense policy which will inevitably have to be made. I also believe that the activities of this Committee would help improve the operational effectiveness of the existing Air Defense Command."

These recommendations were reviewed by the Chief of Staff, who concurred in them and directed the formation of the Air Defense Systems Engineering Committee. Invitations were extended to eminent scientists who could conveniently assemble regularly, and on short notice, in the northeast section of the country where much of the committee's activity is expected to be centered.

## II. MEMBERSHIP AND MODE OF OPERATION

The Air Defense Systems Engineering Committee consists of the following members:

C. S. Draper, Massachusetts Institute of Technology	Aircraft Control
J. Marchetti *, Cambridge Research Laboratories	Radar
A. Donovan, Cornell Aeronautical Laboratory	Aerodynamics
G. Comstock *, Airborne Instruments Laboratory	Radar
H. G. Stever, Massachusetts Institute of Technology	Guided Missiles, Aeronautical Engr.
H. Houghton, Massachusetts Institute of Technology	Meteorology
G. E. Valley (Chairman) Mass. Institute of Technology	Physics

Dr. W. Hawthorne of the Massachusetts Institute of Technology has been assisting the Committee in aircraft propulsion problems.

\* Invited Members



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Major Richard T. Cella has served as Military Secretary to the Committee and as its liaison officer with the Secretariat, Scientific Advisory Board and the Directorate of Research and Development, DCS/D. As of 7 April 1950, Lt. Col. Joseph G. Ferry was appointed Military Secretary to replace Major Cella who reverted to inactive status. Colonel Joseph D. Lee, Jr. usually sits with the Committee as liaison officer with Continental Air Command. The Committee's first formal meeting was held during the last week of December 1949.

The Committee is currently engaged in two distinct phases of its assignment to assist the Air Force with its mission of defending the United States from aerial attack:

(1) To bring the Air Force's presently planned air defense system to its maximum inherent effectiveness.

(2) To develop and test a full-scale, small-area "model" of the best air defense system conceivable, as limited only by basic natural and economic laws.

Like the parent Scientific Advisory Board, the Committee consists of a number of civilian consultants to the Air Force who function together because of their mutual respect and common interest. It is not specifically set up by contract, nor does it administer any contract. It tries to function in as informal a manner as it can and to this end it writes the minimum number of formal reports and makes most of its recommendations verbally to one or the other of the Air Force officials who sit with it. These recommendations are then translated into action by the Air Staff and pertinent field Commands through the coordination of the Military Secretary.

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The Committee meets regularly on Fridays at the Air Force Cambridge Research Laboratories, 230 Albany Street, Cambridge, Massachusetts where secretarial and security services are utilized. Individual members work on various aspects of the problem at other times during the week besides the Friday meetings.

### III. THE AIR FORCE'S PRESENTLY PLANNED AIR DEFENSE SYSTEM

Under this heading will be discussed the United States air defense system as it is now conceived, as well as such new materiel and developments for it as the Committee has so far had time to investigate.

#### A. Mode of Operation:

The present air defense system divides the United States into a number of control areas each of several hundred thousand square miles. Within each control area are to be deployed sufficient (5 to 15) large, ground-based radars which can serve either the functions of early warning or of ground control of interceptions. In each area, there is an Area Control Center which is in communication with each of its radars and with the Civil Defense Air Observer Corps of the pertinent state organizations. The air situation is continuously presented to the area commander by means of a large screen on which aircraft positions are manually plotted from voice telephone information.

At each of the radar stations is a similar but smaller screen which displays only the situation in range of and contiguous to that radar. Its function is twofold: (1) It serves to translate the polar coordinate radar data into latitude and longitude for relaying to the Area Situation

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Board (see above); and (2) it keeps the G.C.I. commanding officer appraised of the local situation.

As it now functions, the area commander directs which radar station is to intercept a given bomber (identified by its position or by an accession number). The assigned station then commits an interceptor and directs it to the task. The actual direction is accomplished by a control officer who works directly from the radar screen and directs the interceptor pilot by voice telephone.

Among others, the following criticism can be made of this as an operational system:

- (1) There is considerable delay in getting information to and from the area commander.
- (2) The general use of voice communication leads to confusion.
- (3) Only a small percentage of the airplanes detected by the radars can be tracked or intercepted.

The general result is that the system is not capable of close coordination and the power of the area commander is thereby limited. This limitation is entirely the result of technical incapacibilities. The system as set up makes the best use of the materiel available.

In addition, there is a very serious and fundamental technical limitation in that the use of large, long-range ground radars allow low-flying aircraft to remain undetected in some regions. A less serious limitation is imposed by the echoes visible from the surrounding terrain which tend to obscure the aircraft echoes in the radars. This effect can be eliminated fairly well but the required auxiliary apparatus

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(M.T.I.) is most delicate of adjustment, and apparently there are very few engineers in the country who even understand its principles.

B. Materiel of Present System on Hand:

There are two different designs of Ground Radar in use.

1. The AN/CPS-5 (L-Band) measures range and azimuth and determines altitude with an auxiliary radar of the nodding beam type (AN/CPS-4 or a derivative thereof). These radars are defective in their high altitude coverage because of lack of power. In field use, they detect aircraft at less than half their calculated maximum range because of faulty receivers.

A new model of this radar, AN/FPS-3, is now on order and is expected to show improved performance in these respects.

The Committee recommends:

a. That the new M.T.I. kits for AN/CPS-5 now on order from Airborne Instruments Laboratory be expedited because their more stable receivers will increase the operational range to the figure which it is generally supposed to be now, as well as the M.T.I. facility which will result.

b. That experiments be performed to see if two or more auxiliary height finders should be used with each AN/FPS-3 radar in order better to monitor target and interceptor altitude.

It is understood that these recommendations have been implemented.

ADSEC is by no means certain that all troubles with the present system have been uncovered even in the restricted field of ground radar. It has been greatly aided in this work thus far by the intimate knowledge

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of the situation displayed by Colonel Lee, Dr. Comstock, and Dr. Marchetti. In order to make this work more effective and to obtain a task-group to carry out the work of correction, it has requested the Air Staff to take the following action:

A development contract with Airborne Instruments Laboratory (similar to Air Defense contract directed by ConAC) be placed under the cognizance of the Cambridge Research Laboratories for FY 51, and its wording include provisions for general consulting, equipment adjustment, and furnishing of good test equipment.

The Committee is now investigating the control and communication equipment in interceptor aircraft. It has not as yet started to look into the aircraft themselves, because the aerodynamic and propulsion situation is generally agreed to be in fair shape. These matters will be studied, however, in the near future.

2. The AN/CPS-6B radar is now being procured from General Electric Company. The first model of this has revealed very serious and basic flaws in the behavior of its associated M.T.I. equipment. The Committee has had a calculation made to see how much in error the altitude indications of this equipment are, due to the high speed of jet aircraft. In the light of these findings, the Committee makes the following recommendation: That the Air Force consider most carefully, whether any operational use can be made of the AN/CPS-6B radars unless they are so extensively redesigned.

A more complete discussion of this matter is presented in Appendix A.

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C. Materiel Proposed for Present System:

(1) 1954 Interceptor: A Special Committee of the Scientific Advisory Board (consisting of Drs. Valley, Astin, Donovan, and Stever) has been requested by the Deputy Chief of Staff, Development to review the electronics and control industry proposals for this weapon and give its opinion with particular reference to new and novel features. This Committee is currently engaged in this work. The results of this study will be available for guidance to the Board of General Officers making final evaluation of these proposals. Drs. Stever and Donovan have visited some of the principal bidders with especial emphasis on those with new ideas. The ADSEC is also having prepared a theoretical study of what the dynamic properties of the electronic control system, including radar, should be, based on the known mean performance of jet interceptors (Dr. Draper).

(2) MX 904 Missile: The Committee has strong doubts that this missile is so superior that it should be considered for the 1954 interceptor to the exclusion of other air to air missiles. The Committee has requested of the Scientific Advisory Board: that the Guided Missile Panel make a searching comparison of the accuracy, damage capabilities and flexibility of performance at various altitudes of Lark, Meteor, Sparrow, MX 904. This work is currently in progress.

(3) Semi-Automatic G.C.I.: The Committee feels that the development and test of this system, whose purpose is to make the G.C.I. controller more effective, should be expedited. Watson Laboratory now has four men working on the device, which is now approaching the testing stage. The Committee recommends: that the project engineer be given the



personnel he needs to prove this device with dispatch. The Committee notes that there is no lack of funds.

(4) Situation Board: If Semi-Automatic G.C.I. is successful, it makes possible the use of a fast and accurate all-electrical situation board. The Committee recommends that steps be taken to procure such a device of the simplest nature as a companion piece to Semi-Automatic G.C.I.

(5) Radar Beacons: This subject is now under discussion; the point being whether MARK X IFF can serve this function, or whether, as some contend, a 5 cm device should be contrived for the purpose. The Committee would welcome the advice of the Electronics and Communications Panel of the Scientific Advisory Board on this, should it care to interest itself in the matter. A radar beacon of some sort is necessary to see our own fighters with pulse radar.

(6) Future Large Ground Radars: There are a number of projects (Army, Navy, and Air Force) developing even larger ground radars than the ones now available. The Committee has been well briefed on the Army 414A program and on the Air Force program. It has not as yet had time to look into the complete Navy program and in particular, it has not yet been briefed on the B.T.L. Mark 65 program. It is not desired to comment on these programs at this time.

#### IV. PROPOSED ADSEC "MODEL" GROUND CONTROL SYSTEM

In reading what follows, it should be borne in mind that these things seem possible to obtain. They can in no sense be guaranteed until painstaking and thorough experimental tests have been accomplished and the results subjected to careful analysis.



A. Basic Ideas Underlying Proposed System:

- (1) The system is to be immobile; erected during a state of peace and in the zone of the interior (including Alaska).
- (2) The system integrated into the civilian economy and industry to the desired extent.
- (3) The system should be capable of functioning at near maximum performance during the first minutes of war.
- (4) The system should be able to control interceptors at all altitudes at which bombers can fly.
- (5) The system should have none of the difficulties of communication which detract from the present system's efficiency.
- (6) The system should not restrict interceptor tactics as compared to present practice, unless such a restriction is counterbalanced by the consequent removal of some other tactical restriction.
- (7) The system should function with both piloted and pilotless aircraft.
- (8) The system should be capable of improvement as far into the future as we can see.
- (9) The system should be capable of orderly installation piece-meal and should utilize as much of the present or presently proposed radar equipment as possible.

A radar set by itself is only a mechanical observation post. There is nothing inherent in the nature of radar which requires that any command function be carried out in close proximity to a radar set. The fact that certain command functions are now so carried out is due to technical limitations.



Similarly, it is because of technical limitations that certain analytical operations such as data filtering are now carried out on radar sites. The present, crude means of communication and filtering make it completely impracticable to forward all the observed data to the control center.

The proposed system functions in these respect in a very different manner from the present system.

It can best be explained by reference to Figure 1.

In Figure 1 an irregular area is shown which is to be defended. It is divided into control areas, each of which has a control center as at present.

Instead of a relatively few large radar sets, there is a large number of small, mass-produced, unattended radar observation posts. These units are connected by ordinary telephone lines (pass-band 3700 cps) to several "data analysers". These in turn are connected together and to the area control center by telephone trunks. Near area boundaries, the same observation post may be connected to data analysers in both areas in order to insure smooth transfer of targets.

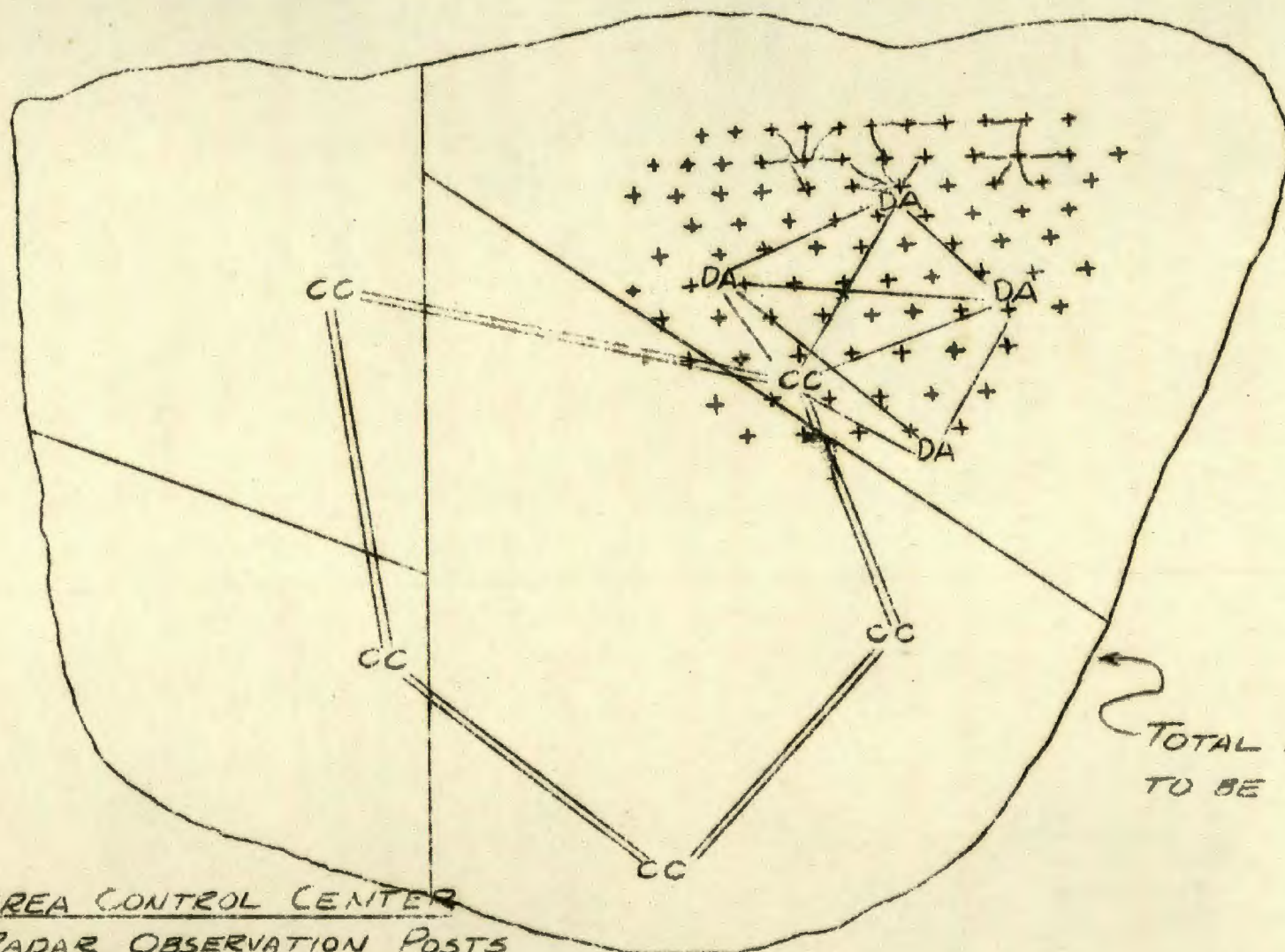
#### B. Observation Posts:

These include CW radars. At a radar frequency of 10,000 Mcps we expect to achieve a slant range of 16 miles on jet fighter with a signal-to-noise figure of 20db. The total power requirement is about 300 watts and 13-15 vacuum tubes are required.

These posts also will include suitable transmitters to give orders to the interceptor. Since orders will be given in A-N code or as direct servo signals to a bearing indicator in piloted aircraft, and as the latter only to pilotless interceptors, these transmitters can be rudimentary affairs.

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FIGURE 1



CC - AREA CONTROL CENTER

+++ - RADAR OBSERVATION POSTS

DA - DATA ANALYSERS

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Also included may be terminal equipment to send the observed data to the data analyser on ordinary telephone lines. If used, this may have either of two general forms: (a) some form of magnetic drum storage device for band compression (compression ratio about 10 to 1) or (b) some form of standard multiplexer to enable the use of several standard telephone channels in parallel.

The use of this terminal equipment must be considered because of the narrow beam requirement on the radars. This makes a high radar transmitter frequency necessary in order that expensive towers need not be erected.

Experiments will also be made with the alternative of using an expensive tower and no terminal equipment. At the moment of writing, this appears to be the less attractive alternative, but this may not always be our opinion.

In any event, the complexity of each observing post will lie between that of a portable radio telephone and that of a console type television set with three speeds of automatic record changer.

Each of these is expected to cost about \$5000.00 installed. About 20,000 would be required for the 2,000,000 square miles to be covered. There would then be a four-fold overlap so that four adjacent posts would have to be knocked out in order to create a gap 10 miles on a side in the coverage. Coverage would be from tree level to maximum altitude. These could be installed and serviced by a civilian commercial organization.

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C. Data Analysers:

In order to get low coverage we must go to small radars in large numbers. In order to do this we must make these radars simple enough to operate for long periods of time (30 days) unattended. Such radars do not yield data which are easily interpreted.

It is the prime function of each data analyser to compute present position of all the aircraft in range of its associated observation posts.

The type of mechanism best suited to perform this function is called a digital computer. It is similar in general idea to an I.B.M. punched card bookkeeping machine, but thousands of times faster.

If such machines are used, we find that they are also capable at no additional cost in complexity of performing any of the following functions as desired:

- (1) Automatic GCI (control signals from transmitter on posts).
- (2) Automatic Target Evaluation (take-off signals by telephone line by shortest route to best airport from pertinent data analyser).
- (3) Automatic Data Filtering.
- (4) Automatic Defense Maneuvers but only according to predetermined strategic principles.

It must be said, however, that the more automatic functions that are required of a given data analyser, the less will be its traffic handling capacity. As more of these features become desirable, more data analysers can be inserted into the system.

It is expected that about 100 data analysers will be required to cover 2,000,000 square miles at a price of about \$500,000 per unit. These could be commercially installed and maintained.



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D. Telephone System:

The commercial Bell System could be utilized in continental United States. In Alaska, radio facilities will be needed at increased cost. The cost of rented wire is \$2.50 per mile per month. Figuring 15 miles of wire per observing post this is \$750,000 per month, if a single pair is used per post.

We believe that the large number of these posts and their overlapping coverage will render them relatively proof against sabotage.

E. Method of Operation:

What follows is only one suggested method of operation. We envisage a minimum of use of IFF equipment. Aircraft will be identified generally by being tracked from airport to airport according to flight plan. This will be done automatically and flight plans will be filed with the system upon take off.

Aircraft entering ZI must do so through ports of entry where they can be identified by radio, by search-light carrying aircraft or by any other means. Aircraft off-course and entering at points not designated as ports of entry, will be brought down unless scheduled.

If some such legal procedure as the above is unsatisfactory, the system can be fitted with a type of IFF. However any radar system, including the present one, which can have an IFF system can also be more readily jammed. In this connection, we foresee the possibility, if IFF is not required, of making a system which can function on angle data only and is thus jam-proof to some degree.

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F. Over-water Coverage:

Over-water we have no such pretty system to present. Probably a combination of the following will have to be used, as geography demands:

- (1) Buoys or boats supporting CW observation posts.
- (2) Large shore-mounted low precision ground-wave radars whose beams will give crude data but which should curve around the earth's surface (only usable over water, and possibly dependent on atmospheric conditions).
- (3) Picket boats as now proposed.
- (4) AEW

All these can in principle be tied into the system's data analysers.

G. Use of Present Equipment:

The data analysers will also accept data from radars of the type now in use and initially these would form a part of the system. The system would not achieve low coverage through the use of these large radars, however.

H. Recommendations:

In order to carry out experiments to see if the many attractive features described above can be realized, ADSEC has recommended to the Air Staff that;

- (1) The Raytheon Mfg. Co. and the Federal Tel & Tel Co. be authorized to construct several CW radar sets to committee specifications.
  - (2) The Air Force support, in part for FY 51, the Whirlwind Digital Computer. This device is to serve as an experimental data analyser.
- [REDACTED]



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(3) That certain facilities of Cambridge Research Laboratories be directly applied to these experiments.

(4) A program to study ground wave radar be supported (Raytheon).

It is expected that first phase experiments on the above equipments will begin in September 1950. These tests will then be extended to include all elements of the "model" system which it is contemplated will be set up on a small geographical scale in the New England area. When the complete system has been integrated and made workable, it will be demonstrated to the Air Force. As outlined above, it is so designed that it can be expanded to the geographical size which military requirements indicate.

I. Interceptor Control Equipment:

There is considerable talk of a "pilotless interceptor" in Air Force circles. Although it is generally agreed that such a device can be made, it does not seem to be thoroughly recognized that very delicate technical issues are at stake. In particular, the dynamic properties of the airplane itself must be carefully determined and the properties of the electronic equipment suitably adjusted to fit. The Committee feels that such determination should be made now and has recommended that the MIT Instrumentation Laboratory be authorized to do this work. While the proposed ground control system will work with either manned or unmanned interceptors the latter are preferred as being cheaper and simpler.

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V. OTHER DEVELOPMENTS

The ADSEC has just begun to consider what simplifications can be made in pilotless interceptors, when safety requirements are removed.

It is obvious that, given data at all altitudes, we need an airborne radar which will also work at all altitudes. Since the active homing head for the "Lark" missile has already fairly suitable properties in this respect, consideration of an Air Force development program has been temporarily deferred.

Dr. Houghton is investigating what needs to be done in order to get sufficient meteorological data to prepare a map showing critical wave-trapping areas in and contiguous to Z.I.

Informal discussions have been initiated with Bell Telephone Laboratories concerning various features of the proposed ground control system.

VI. PROJECT BUDGET

The budget which has been set up to cover the work of the Air Defense Systems Engineering Committee is shown below. The Committee has no direct control over the administration of these funds. They are disbursed through conventional Air Force procurement channels and pertinent contracts are administered by appropriate Air Materiel Command agencies.



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	FY * 1950	FY ** 1951
"L" Band Radar	\$100,000	\$150,000
"X" Band Radar	100,000	150,000
Project Whirlwind		600,000
Digital Terminal Equipment		200,000
Ground Wave Study		50,000
Air Defense Systems Study	100,000	100,000
Control Study of Interceptor Aircraft		400,000
	<hr/>	<hr/>
TOTAL	\$300,000	\$1,650,000
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\* Obligated  
\*\* Planned

/s/ George E. Valley, Jr.  
GEORGE E. VALLEY, JR.  
Chairman, ADSEC  
7 April 1950

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Watson Laboratories, AMC  
Red Bank, New Jersey  
23 March 1950

Dr. George E. Valley  
Massachusetts Institute of Technology  
Cambridge, Massachusetts

Dear Dr. Valley:

Inclosed you will find a copy of an elementary computation of the height error introduced in a V-beam system due to target motion. This computation was undertaken at your suggestion made at the 17 March 1950 meeting of the Air Defense Committee.

It is hoped that the approximate results given will be adequate for discussion purposes since they will yield magnitude of error to better than 10% accuracy. The results were given verbally to Dr. Comstock when he visited our installation on 22 March. Unfortunately, the material could not be typed until 23 March.

I hope that the report will reach you in time for your next meeting. If you should require any further assistance in this matter or any other, I shall be glad to oblige.

Very truly yours,

  
JEROME FRIEDMAN

1 Incl  
Tech Memo



## TECHNICAL MEMORANDUM

23 March 1950

HEIGHT ERROR IN THE V-BEAM RADAR  
DUE TO TARGET MOTION

## I. INTRODUCTION

The principal of computing height in the V-beam radar is to reduce the observation of elevation angle to an observation of a displacement in azimuth angle. This angular displacement is the angle required to be traversed by the antenna mount to observe the target in the beam slanted at  $45^\circ$  after the target has been observed in the ordinary search beam. During the time that the antenna mount is traversing this angle the target may move and this motion will cause an error in the measured angle and hence the height computation. An approximate computation of this error is made which assumes motion in all other parts of the system and neglects beam thickness.

II. The basic equation for computing height in a V-beam system is given in Ridenour, "Radar System Engineering" page 294 for a  $45^\circ$  V-beam system:

$$H = \frac{R \sin \theta}{(1 + \sin^2 \theta)^{1/2}} \quad (1)$$

where:  $H$  = target height

$R$  = slant range of target

$\theta + \theta_0$  = angle turned by the mount

$\theta_0$  = fixed offset angle of  $10^\circ$

The expression assumes very thin vertical and slant beams and also assumes no motion of the target.

The error in the height computation due to tangential motion of the target about the radar set may be computed by differentiating (1) with respect to  $\theta$ .

$$dH = \frac{R \cos \theta}{(1 + \sin^2 \theta)^{3/2}} d\theta \quad (2)$$

The value  $d\theta$  in terms of target tangential velocity and antenna rotation rate is given by:

$$d\theta = \frac{V \sin \alpha}{R \omega}$$



where:  $v_e$  = tangential target velocity

$T_s$  = time in seconds per antenna rotation

$R$  = slant range to target

Combining (2) and (3)

$$\Delta H = \left( \frac{\theta + \theta_0}{2\pi} \right) \left( \frac{\cos \theta}{(1 + \sin^2 \theta)^{3/2}} \right) v_e T_s \quad (4)$$

$\theta$  is eliminated from this expression by using:

$$\sin \theta = \tan B \quad (5)$$

where:  $B$  = angle of elevation of target

Giving:

$$\Delta H = \left[ \frac{\theta_0 + \sin^{-1}(\tan B)}{2\pi} \times \frac{(1 - \tan^2 B)^{1/2}}{(1 + \tan^2 B)^{3/2}} \right] v_e T_s \quad (6)$$

The function of  $B$  contained in the brackets of (6) may be closely approximated in the region  $B = 0$  to  $B = 25^\circ$  by:

$$F(B) = \frac{\theta_0 + B - .015B^2}{360} \quad (7)$$

where  $B$  is in degrees.

Giving finally a result for  $\Delta H$ :

$$\Delta H = \left[ \frac{\theta_0 + B - .015B^2}{360} \right] v_e T_s \quad (8)$$

In fact a reasonable approximation which gives a simple result by neglecting  $.015B^2$  is:

$$\Delta H = \frac{\theta_0 + B}{360} v_e T_s \quad (9)$$

It may be seen from (9) that the height error to a good approximation is simply the tangential distance the target may travel during the interval that height is being measured.

There is a question concerning the accuracy of the method for large error. The desired result is:

$$\Delta H = F(B) \Delta \theta$$



The expression for  $\Delta H$  is given by:

$$\Delta H = F(B) \cdot d\theta \quad (11)$$

The height  $H$  as a function of  $B$  or  $\theta$  is a monotonically increasing function in the region of interest ( $0 < B < 30^\circ$ ). The slope of the function is such that  $dH$  is always greater than  $\Delta H$ .

In any case the error in the error computation will be small if the value of  $d\theta$  is small. The value of  $d\theta$  is given by equation (3). Putting in this equation the largest values for the parameters, i.e.

$$V_t = 600 \text{ mph}$$

$$T_R = 30 \text{ sec (2 RPM)}$$

$$\theta_0 = 10 \text{ degrees}$$

$$\theta = 25 \text{ degrees (maximum coverage angle)}$$

$$\text{Maximum } d\theta \text{ in degrees} \approx \frac{30}{R \text{ miles}} \quad (12)$$

It can be seen then that for ranges greater than 10 miles the error computation will be reasonably accurate.

Using (6) as a basis for computation, a plot of height error versus a normalized factor

$$\frac{V_t}{\text{RPM}}$$

is shown for the two extreme cases of elevation angle namely  $B = 0^\circ$  and  $B = 25^\circ$ .

$$\Delta H = 100 \left[ F(B) \right] \frac{V_t}{\text{RPM}} \quad (13)$$

where:  $F(B)$  is obtained from (6) for  $B=0^\circ$ ,  $B=25^\circ$

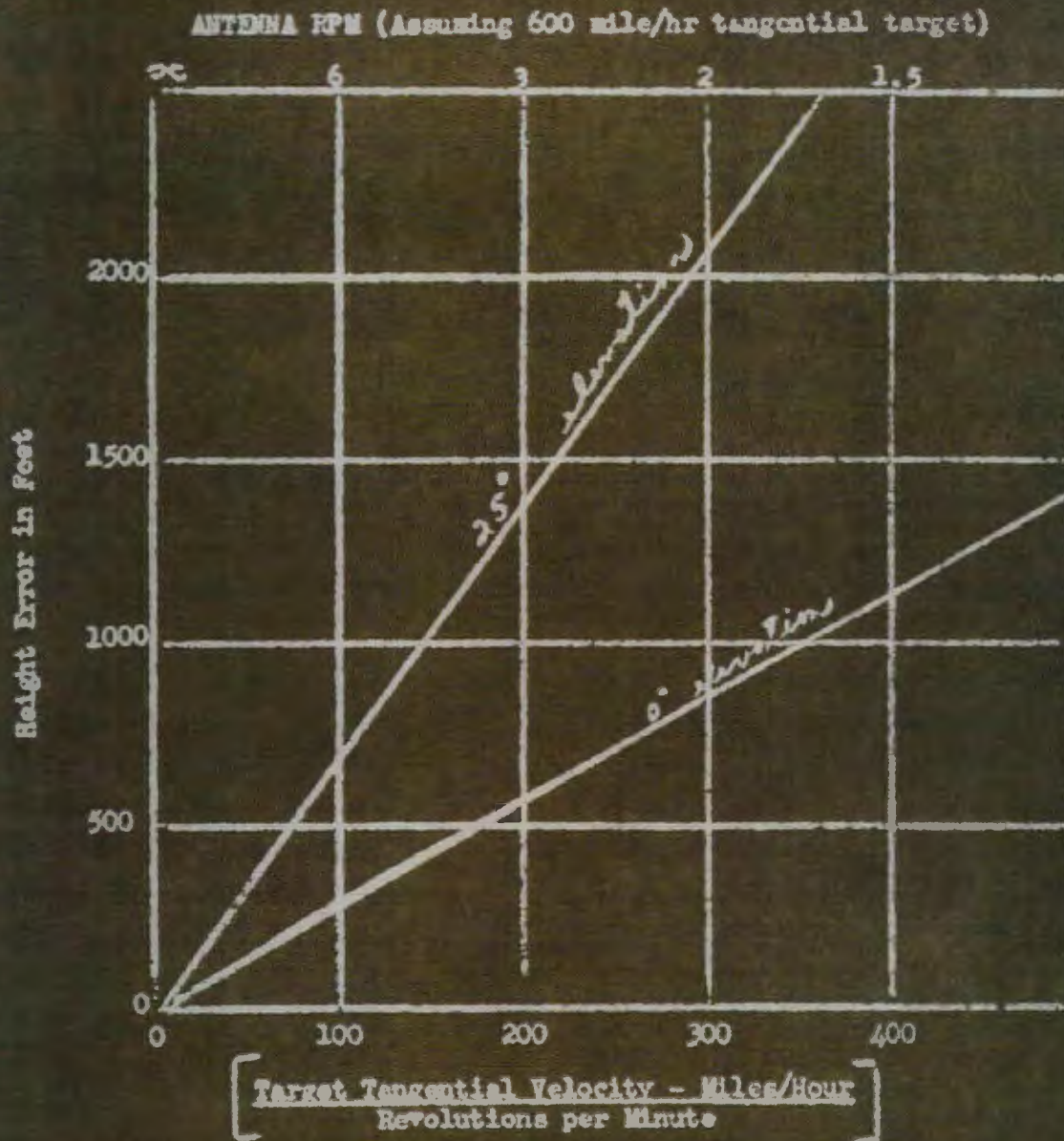
$V_t$  = tangential velocity in miles per hour

RPM = antenna revolutions per minute

Insofar as radial velocity is concerned there need be no error in the height computation provided that the range in the slant beam is used as a basis for compensation.



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HEIGHT ERROR OF V-BEAM RADAR  
DUE TO TANGENTIAL TARGET VELOCITY

FIGURE 1

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The height error in a V-beam system, to a good approximation is simply equal to the tangential distance a target may travel during the interval that height is being measured. The height error due to tangential target motion is presented graphically in figure 1 against a normalized coordinate ( $V_c / \text{RPM}$ ). This height error is composed of two parts, the first due to the offset angle of the V-beam, the second due to target elevation angle. The initial error contributed by the  $10^\circ$  offset angle is about 25% of the maximum error attained. It is seen that for much 1 target velocities and high elevation angle this error can become quite serious. The relative error between two targets having opposite tangential velocities will be twice the error indicated. The relative error between two targets having tangential velocities in the same direction will tend to cancel out. Ordinary flight tests on the system will not show the type of error being discussed. This is because test flights are usually flown on a radial path. There will be no computing error due to radial target motion if the range measurement used in the computation is that obtained in the V-beam. The display indicator is so arranged that the operator will normally compute height in this manner.

The error due to tangential target motion is a systematic error and may be eliminated from the height computation provided that tangential velocity of the target ( $v_t$ ) is measured. This velocity may be obtained from the target track although this computation is not ordinarily performed. With a knowledge of the tangential target velocity a set of correction curves may be applied to the computed velocity. This process will not ordinarily be necessary except for high angle targets. This operation is a laborious addition to the ordinary visual display height computation. However, it is a correction that may be inserted in track-while-scan circuitry with no imposing difficulties since velocities are already computed in these devices for prediction purposes.

Other possibilities for minimizing this error are operation at high antenna rotation rates, elimination of the offset angle and crossing the normal and V-beam at their centers rather than their bases. A maximum upper limit on rotation rate is imposed by other considerations. Eliminating the offset angle and changing the point of beam intersection require an antenna electrical and structural redesign and a new indicating system which does not appear to be warranted.

If no attempt is made to eliminate the systematic error due to target tangential velocity, then for high elevation angles and much 1 speed the height computation even at 6 RPM may be marginal.

THIS COMPUTATION WAS UNDERTAKEN AT THE REQUEST OF DR. GEORGE VALLEY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

5  
JEROME FREEDMAN  
Engineer, Radio



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March 30, 1950

Dr. George E. Valley, Chairman  
Air Defense System Engineering Committee, SAB  
Massachusetts Institute of Technology  
Cambridge, Massachusetts

SUBJECT: Problems Concerned with the AN/CPS-6B Radar

Dear Dr. Valley:

This discussion concerns itself with several problems that have arisen in connection with the present production program of 16 sets of the AN/CPS-6B. Three items will be mentioned:

- (A) Inadequacy of present MTI system,
- (B) Limitation of present CPS-6B as an EW station when using 600 pps repetition frequency required for MTI operation,
- (C) Intrinsic limitation of height accuracy of the CPS-6B for high speed, high altitude tangential targets.

## A. Present MTI System

The present system operates with a 600 pps repetition frequency limiting the range of the set when operating with MTI to a maximum range of 130 nautical miles. MTI is incorporated on the lower and center portions of the vertical search beam and on the lower portion of the slant beam.

A careful examination of the MTI performance in late January and February of the first production model at General Electric, Syracuse, with AIL engineers as consultants to General Electric, has revealed serious deficiencies that will require fairly major modifications to the set before good MTI performance can be assured. General Electric engineers are engaged in an intensive component testing and improvement program with the aim of demonstrating a "doctored up" set operating satisfactorily

UNCLASSIFIED



March 30, 1950

at 6 RPM around the latter part of April. It is anticipated that a minimum of six months will then be required to incorporate necessary improvements into production form.

The CPS-6B MTI system must therefore be considered as still in development stage. The major problems and components which require solving or improving are:

1. magnetron instability

- (a) Addition of filter to modulator high voltage supply to eliminate FM'ing on magnetron.
- (b) Reduction of ripple in magnetron filament supply.

2. Coho instability

- (a) Reduction by a factor of 2 or more of the ripple in power supply.
- (b) Modification of coho locking circuit

3. Stalo instability

Very serious jitter troubles exist in the present Stalo. It may be necessary to completely replace stalo with another type.

4. Poor phase detector characteristic.

Phase detector characteristic is approximately sinusoidal rather than triangular.

5. Excessive vibration of components.

It may be necessary to improve the vibration isolation of the transmitter and internally of the numerous blowers.

6. Cancellation circuits

A thorough check must be made of the behavior of the cancellation unit as inadequate data are available as to its performance.

With the exception of the eventuality of a new stalo, it should be possible to incorporate these modifications into production six months after testing the complete modified system.



It is obvious that if CPS-6B's are required in the field before the completion of the MTI improvement program, they will have to be sent out sans MTI. It is also apparent that in any additional procurement programs for CPS-6B, these necessary MTI modifications may effect any presently contemplated delivery schedule.

One other question concerning the MTI system has been investigated, namely, the apparent velocity of fixed ground targets relative to antenna motion introduced by the fact that neither the vertical or slant reflectors are mounted at the center of rotation of the antenna system. This apparent velocity of fixed targets is proportional to the product of antenna rpm and the radius of displacement from the center of rotation.

The following table shows peripheral speeds as a function of antenna rotation speeds.

	<u>Rotational Speeds</u>	<u>Peripheral Speeds</u>	
	(RPM)	Center of reflector (mi/hr)	Outside edge of reflector (mi/hr)
Vertical beam	3	1.6	4.3
(Offset radius	6	3.1	8.5
= 7 1/3 ft)	15	8.0	21.5
Slant beam	3	1.3	3.6
(Offset radius	6	2.5	7.3
= 5 7/8 ft)	15	6.3	18

From measurements made on other MTI systems, it can be stated that, with a properly designed phase detector, an S-band MTI system operating at 600 pps should give adequate cancellation of targets with apparent speeds toward or away from the radar of less than 5 mi/hr. (This statement is fairly well substantiated by tests made in 1947 at Cambridge Research Labs where an eccentrically mounted SCR-584 dish was tested on a CPS-1 radar. Peripheral speeds of approximately 4.5 mph were used with an MTI system with a 300 pps repetition rate giving fair cancellation of fixed targets at 3 RPM and poor cancellation at 6 RPM.)

Without special compensation for this effect, a CPS-6B at 6 RPM and 600 repetition rate should show only partial cancellation of ground targets, since radiation received by the outermost portions of the reflector would exceed a relative velocity of 5 mph.



However, in the actual CPS-6B MTI design, a compensation proportional to antenna rotation speed is introduced to correct for the apparent motion of the center of the antenna reflector. This correction is accomplished by continuously changing the phase of the MTI coherent oscillator output in such a way as to establish a constant ratio between the phase shift rate of change and the rpm of the antenna reflector so that the echo reference voltage to the phase detector will have the same phase shift as the pulse-to-pulse shift of fixed target echoes.

With this correction, apparent motion due to radiation falling outside the central portion of the reflector will be reduced to velocities small enough to be insensitive to the phase detector. Hence it can be assumed that the effect of the eccentricity of the antenna rotation has been correctly compensated for.

#### B. Limitation of Present CPS-6B as an EW Station

The present CPS-6B is equipped with two repetition frequencies 300 and 600 pps. The 600 rate is used with MTI operation; however, with its use the interval between "main bangs" is 135 nautical miles limiting the indicator sweep length to between 120 and 130 nautical miles. (No MTI gating method is used so that MTI can be used only over the ground cluttered portion of the sweep as in the CPS-5 and FPS-3 MTI.)

Inasmuch as the requirement exists for the set to be used simultaneously as a GCI and an EW station at locations where ground return will be severe, some provision must be made to obtain both longer range sweeps and satisfactory MTI simultaneously. Two general solutions have been considered at Watson Labs: Use of a 300 pps MTI system with the rotation speed reduced to 3 rpm; and addition of a separate EW beam to the vertical beam by adding another transmitter and feed system.

A satisfactory 300 rep. rate MTI could be produced for the set, but experience has indicated that 3 RPM is too low a rotation speed to give adequate GCI operation by present methods. Furthermore, excessive height errors, as discussed in Section C, may be introduced by the geometry of the CPS-6 at 3 RPM rotation speed. A 300 rep. rate MTI would show poor cancellation at rotation speeds much above 3 RPM.



March 30, 1950

Three possibilities are being considered by Watson Labs. for the addition of a separate EW beam (Watson Labs. now has an Air Force Headquarters directive to modify the CPS-6 by this method) namely:

1. use of another CPS-6 transmitter and offset feed,
2. use of an APS-20A transmitter and offset feed,
3. use of an L-band transmitter (repackaged FPS-3 components) with an on-center split horn feed designed around present lower beam feeds.

Either of the first two methods would involve the addition of a horn feed off set from the focus which would produce a beam with an azimuth "squint" of about 6°. This would require that early warning be done on separate PPI's from those used in the rest of the system.

The use of another of the present transmitters is attractive from the maintenance viewpoint. It is probable that sufficient room could be made on the mount for it. However, there would be a considerable problem in finding space in the frequency spectrum for the extra beam. Two tunable magnetrons are used in the present system; one 2700-2900 mc, the other 2900-3100 mc. The five beams are kept in the following ranges; 2700-2740, 2740-2780, 2820-2860, 2965-2992, 2992-3019 with a 30 mc. IF used. There has been a considerable problem in adjusting operating frequencies so that no interference between beams occur. A six beam in the same range might be prohibitive from the interference standpoint, although it should be possible with proper modification of receivers to achieve isolation.

The use of the 3400 mc AEW transmitter (APS-20A) was suggested by G.E. because of this interference problem and its smaller size. However, it is 400 cycle gear that would require the addition of a converter. Also it is in the airborne S-band region where the Air Force has no other equipment and hence no proper test equipment.

The third possibility of the addition of L-band repackaged FPS-3 components for transmitter would add equipment that will be familiar to the Air Forces; test equipment, and maintenance training is less of a problem. Furthermore, this furnishes the ability to add a beam without azimuth "squint". The present beams are vertically polarized. If horizontal polarization is used for the EW beam, a split beam horn can be designed to envelop the present lower and outer feeds and produce an on-center beam. This



Dr. George E. Valley

-6-

March 30, 1950

problem has been properly solved before at AIL and could be done again. (It is impossible to use the cross polarization scheme on S-band since the diamond-shaped reflector mesh is such a size that severe transmission losses through the dish would be incurred.

Calculations of the gain of the antenna gives approximately 33 db which results in usable early warning ranges at least equal to and probably 10 percent greater than the present low beam of the CPS-6B. Flight tests with B-17's have given 175 mile ranges with the 300 rep. rate. The use of L-band would widen the azimuth beam width to approximately  $2.3^\circ$  and the elevation beam width to about  $5^\circ$ . The azimuth widening is not a serious problem in early warning, although it would be for GCI; the elevation widening gives additional high coverage protection.

The main disadvantages to the L-band idea are the unknown factors of the time required for the repackaging of FPS-3 components and for the horn redesign. It now appears that Watson Labs. is collecting the facts necessary to make the choice, but will chiefly need continuous prodding for a speedy answer.

C. Since a memorandum by J. Freedman of Watson Labs on the calculation of height error in the CPS-6B due to target motion is available, its conclusions only will be summarized here. A computation has been made of the height errors introduced on tangential targets or those with larger tangential component of motion by the motion of the target in the interval between its being scanned by the vertical and horizontal beams; this computation assumed perfection in all other parts of the system and neglected beam thickness.

The height error is found to be, in the first approximation, simply the tangential distance a target may travel during the interval that height is being measured. It is made up of two parts: that due to the  $10^\circ$  offset azimuth angle between the beams and that due to target elevation angle. The former is about 25 percent of the maximum error. An example of the error magnitude is given for 600 mi/hr tangential velocity. At 6 RPM antenna rotation height error is 300 ft. at  $0^\circ$  elevation angle and 700 ft. at  $25^\circ$  elevation angle; for 3 RPM the corresponding errors are 600 and 1400 ft. Two targets having opposite tangential velocities such as a bomber and interceptor on a head-on collision course would



UNCLASSIFIED

Dr. George E. Valley

-7-

March 30, 1950

exhibit a relative error of twice that indicated. It is seen that for high tangential speeds and high elevation angles, this source of error is indeed serious. It may not be so serious with presently anticipated targets, but certainly the V-beam principle is intrinsically a poorer height finding system as the missile era is approached.

Of course if the tangential velocity of the targets are known (as in automatic track-while-scan systems) correction can be made to the height computation. However, a different correction would have to be made to each target, which would be a somewhat laborious process.

GCC:vec

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